Timing and Measurement of Weed Seed Shed in Corn (*Zea mays*)[1]

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Abstract: In west central Minnesota the extent and duration of weed seed shed was measured for two years in corn that received cultivation but no herbicides. Percentage of seed production represented by viable (filled) seeds was about 79% for green foxtail, 68% for wild mustard, 49% for Pennsylvania smartweed, 48% for common lambsquarters, and 35% for redroot pigweed. Percentage viable seeds varied from 11% in 1993 to 59% in 1994 for redroot pigweed, but was more stable for other species. Seed shed commenced in late August in a cool year (1993) and early August in a warm year (1994). Average growing degree days (base 10 C) from corn planting until 25% seed shed was 983 for common lambsquarters, 984 for wild mustard, 1004 for Pennsylvania smartweed, and 1034 for both green foxtail and redroot pigweed. Brief weather events, such as wind storms, dispersed large percentages of total seed production within a single day. More than one-fifth of all viable seeds of green foxtail, redroot pigweed, and common lambsquarters were retained by the seedheads and dispersed by combines at harvest. In contrast, seeds of early-maturing species, such as wild mustard, were completely dispersed before corn harvest in the warmer year, but one-third of seeds were retained by seedheads at harvest in the cooler year. Measurement of seed shed was compared using five seed trap designs. The preferred design consisted of a 10-cm-diam plastic cup, whose bottom was replaced by a brass screen, and the entire unit attached to a small wooden stake for support. This design provided, on average, the highest estimates of seed production, least among-replication variability, highest correlation with weed population density and aboveground dry-weight, lowest assembly cost, and greatest ease for sample access and seed processing. **Nomenclature:** Common lambsquarters, *Chenopodium album* L. #[3] CHEAL; corn, *Zea mays* L; green foxtail, *Setaria viridis* (L.) Beauv. # SETVI; Pennsylvania smartweed, *Polygonum pensylvanicum* L. # POLPY; redroot pigweed, *Amaranthus retroflexus* L. # AMARE; wild mustard, *Sinapis arvensis* L. # SINAR; and wild proso millet, *Panicum miliaceum* L. # PANMI.
Additional index words: Phenology, seed dispersal, seed production, seed rain, seed traps.

INTRODUCTION

Weeds that escape control in crops often produce abundant seeds (2, 3, 11). If these seeds mature before the crop, they may be dispersed by wind, water, or animals. In contrast, if the weed seeds mature with the crop, they are more likely to be dispersed by harvesting machinery or with harvested grain (6). The timing of seed dispersal relative to crop harvesting may have important consequences for weed species survival within fields, the rate of weed spread within and among fields (10), and effects on subsequent crop yield losses (9). Additionally, successful application of herbicides with rollers or rope-wick applicators depends upon the timing of weed seed maturation (2) and must occur before the beginning of seed shed.

Only a few studies have reported the duration of weed seed shed, and these were mostly from small grain fields in northern Europe (4, 6, 15). For example, in winter barley (*Hordeum vulgare* L.) in England, 53% of wild oat (*Avena fatua* L.) seeds were dispersed before harvest, and the remaining 47% dispersed during harvesting operations (15). Other reports have documented weed seeds dispersed by combine harvesters (13), without enumeration of seeds dispersed prior to crop harvest. Little is known about the duration of weed seed dispersal in spring-sown crops, especially row crops such as corn.

Weed seed production usually is measured by one of two methods: the individual-plant method, and the unit-area

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821-3133.

method. However, there have been no critical evaluations of methods to measure weed seed production and duration of seed shed. The first method for measuring weed seed production typically involves periodically harvesting fruit from individual plants as they mature. This method works well for species whose seed are produced in infructesences (fruit-bearing infloresences) in which fruit are relatively large and indehiscent, e.g. capsules of velvetleaf (*Abutilon theophrasti* Medikus) (3) and jimsonweed (*Datura stramonium* L.). Although the method is not well-suited for species whose seed are produced in infructesences in which individual fruit are small, mature sequentially, and readily disarticulate or dehisce (e.g., Palmer amaranth, *Amaranthus palmeri* S. Wats.), it often is used for these species because it is convenient (8).

The unit-area method for measuring weed seed shed can be applied through a number of means. After dispersal, large seeds of species such as common cocklebur (*Xanthium strumarium* L.) can be counted from known areas of soil surface. Similarly, portable vacuum cleaners can be used to retrieve seeds on the soil surface. This method works well in dry environments, but it is not reliable if heavy rains embed weed seeds in soil or if considerable crop debris covers the soil surface.

The unit-area method more commonly employs seed traps. Many different types of seed traps exist. A frequently used type of seed trap consists of a petri dish coated with a long-lasting adhesive (14). In agricultural fields these devices trap weed seeds, as well as an annoying amount and variety of debris (e.g., crop leaves, stems, insects, soil particles). Such debris causes difficulty in isolating and counting weed seeds. The adhesive also sticks to the forceps that are used to remove seeds (for viability tests), and overlying debris, making the process a laborious task. Other types of seed traps have included boxes or funnels, typically covered by screens to deter animals and exclude large plant debris (12). These types of traps are often heavy, clumsy, difficult to construct, and expensive. Despite problems associated with seed traps, they have proven useful in estimating seed shed. However, the reliability and utility of different types of weed seed traps have never been examined systematically, although one laboratory study did compare five trap designs for simulated rangeland conditions (7).

The first objective of this study was to compare the duration of weed seed shed between years and among species of weeds growing in corn. The second objective was to test several seed trap designs in field plots of corn to determine which designs enable rapid isolation and enumeration of weed seed density, reduce among-plot variability, and can be constructed from cheap, durable, and readily available materials.

MATERIALS AND METHODS

In 1993 and 1994 weed seed shed was measured in four corn plots in which weeds were not controlled except through interrow cultivation. Previous crops were soybean (*Glycine max* (L.) Merr.). Plots were located on a Barnes loam soil (Pachic Udic Haploboroll, fine, mixed, mesic) at the Swan Lake Research Farm, Stevens County, MN. Soil was moldboard-plowed in autumn, and field-cultivated and harrowed immediately before sowing. Corn ('Pioneer 3790') was sown on May 17, 1993, and May 16, 1994. Plots were 18.2 m long and 9.1 m wide, and consisted of 12 rows of corn. Row width was 76 cm and the corn population was 75,000 plants/ha. Starter fertilizer was applied at sowing at the rate of 10, 30, and 30 kg/ha equivalent of N, P, and K, respectively. The equivalent of 100 kg/ha of N was applied and incorporated with a cultivator in June when corn was about 30 to 40 cm tall.

Phenology of seed shed. Duration of seed shed was measured by placing six seed traps along a diagonal line in the central 6 by 15 m portions of each plot (Figure 1). The traps were constructed from 10-cm-diam plastic cups that were

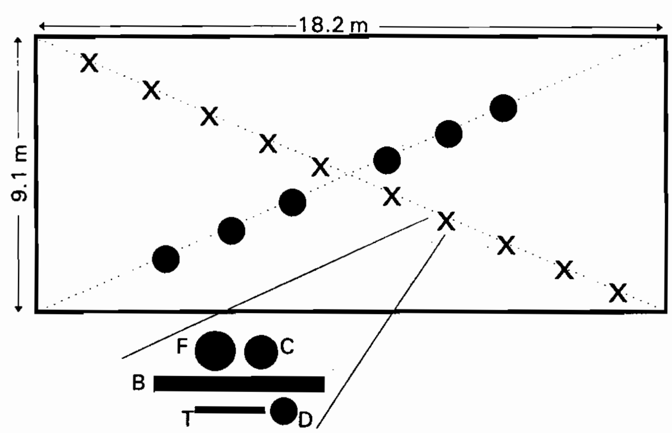

Figure 1. Schematic plot diagram showing placement of seed traps in each of the two experiments. In the phenological experiment six traps (solid circles) were placed along a diagonal line within the central 6- by 15-m portion of each plot. In the trap comparison experiment, five types of traps were placed at each of 10 locations (x's) along a diagonal line within the central 8 by 16 m portion of each plot. The openings of the five traps differed in size and geometry as described in the text: B, board; C, cup; D, dish; F, funnel; and T, trough. The C, D, F, and T traps were randomly positioned near the midpoint of the B trap at each location. The schematic is not drawn to scale.

taped to small wooden stakes. The stakes were driven into the soil to keep the cups erect. The tops of the cups were about 15 cm from the soil surface. Small holes were cut into the bottoms of the cups to facilitate drainage of rain water, but seeds were retained by insertion of brass screens whose mesh was small enough (0.4 mm) to retain seeds of the smallest-seeded weeds in the study area.

Seed traps remained in the plots from early August, prior to seed dispersal, until after corn grain harvest in October. Immediately before harvest, traps were positioned in the corn rows to avoid damage by harvesting machinery. Trapped seeds were collected from the cups on a weekly basis throughout the period of seed shed, including immediately before and after corn harvest. Weed seeds were not observed in harvested corn grain samples, indicating that most weed seeds were dispersed by harvesting machinery.

At each sampling date, all seeds were identified to species, separated into "viable" and "non-viable" categories, and counted. Non-viable seeds were those that crushed when probed with fine-tipped forceps, whereas viable seeds remained firm under pressure. Percentages of seeds shed during each sampling period were calculated by dividing the numbers for each sampling period by total seasonal seed production and multiplying by 100.

Weed seed production per plant, or fecundity, was calculated by dividing total seasonal seed production (seeds/m^2) by the population density (plants/m^2) of weeds that occurred in the plots. Weed densities were determined in July by counting the number of individuals within six 25- by 40-cm quadrats in each plot. At the same time aboveground dry-weights were determined for each species by clipping plants in the same quadrats and then oven-drying.

Daily weather data were collected at the nearby Univ. of Minn. West Central Exp. Stn. Growing degree-days (GDD[4], base 10 C) were calculated and summed from the day of corn sowing to harvest in each year. Maximum and average wind velocities were determined for each day from August through corn harvest date.

Data were analyzed using ANOVA and LSD ($p = 0.05$) to determine differences in seed production among weed species; species were considered "main treatments," and where appropriate, years were considered "sub treatments" (1).

[4]Abbreviations: CV, coefficient of variation; CV_{td}, CV for seed density; CV_{tf}, CV for seed fecundity; CV_{wd}, CV for weed density; CV_{ww}, CV for weed dry weight; DOY, day of year; GDD, growing degree-days; r^2, attributable variability.

Comparison of seed traps. Five types of seed traps were compared in 1993 in the plots described above. There were three reasons for choosing the differing designs for the traps that were compared. First, the materials were readily available and relatively inexpensive. Second, some of the trap designs had been used by other research teams. Third, the trap designs differed considerably in surface area, shape, and surface texture (adhesiveness), all of which conceivably could affect seed entrapment. Descriptions of these trap designs follow.

Cup: This trap was a circular plastic cup, as described above, with a 10-cm-diam opening at top and a 10-cm height. Holes were cut in the bottom for drainage, above which a brass mesh screen was inserted to retain seeds. A wooden stake was attached for soil support. The top rim of the cup was about 10 to 15 cm above the soil surface. Raw material cost was estimated at \$0.30, and assembly time was estimated at 3 min.

Funnel: This trap consisted of a circular 15-cm-diam aluminum funnel, with a brass mesh screen inserted above the drain tube to retain seeds. A wooden stake was attached for soil support. The top rim of of the funnel was about 15 cm above the soil surface. Raw material cost was estimated at \$3.60, and assembly time was estimated at 10 min.

Trough: This trap was a rectangular 2.5 cm by 33 cm aluminum trough with 2-cm-high side walls. The top of the trap was covered by a debris screen with 2-cm-wide mesh. The ends of the trap were attached to steel stakes for soil support. The top rim of the trough was about 10 cm above the soil surface. Raw material cost was estimated at \$4.00, and assembly time was estimated at 20 min.

Dish: This trap was a circular petri dish with a 9-cm-diam and 0.5-mm side walls. The inside bottom of the dish was coated with a non-toxic, resin-like adhesive that stayed tacky even after long periods of rain. The top rim of the dish was 1 to 2 cm above the soil surface. Raw material cost was estimated at \$0.12, and assembly time was estimated at 1 min.

Board: This trap was a retangular 3.8 cm by 76 cm flat wooden board (lath). Its top side was coated with adhesive (as above). The top of the board was about 1 to 2 cm above the soil surface. Raw material cost was estimated at \$0.20, and assembly time was estimated at 5 minutes.

A trap of each type was placed in early August at each of 10 points along a diagonal line spanning the 10 central interrow areas in each plot (Figure 1). The board trap spanned the interrow distance (76 cm) from one corn row to the next. At each point other traps were randomly

Table 1. Densities of viable and non-viable seeds, and percentages of viable seeds, produced in 1993 and 1994 by five weed species in corn near Morris, MN.

Weed species	Seed density				Viability	
	Viable		Non-viable			
	1993	1994	1993	1994	1993	1994
	no./m²				%	
Green foxtail	25,600 a[a]	14,000 a	6376 a	3922 a	80 a	77 a
Redroot pigweed	207 b	742 b	1574 b	509 b	11 d	59 ab
Common lambsquarters	2,518 b	127 b	4701 ab	111 b	42 c	54 b
Wild mustard	4,076 b	874 b	2396 ab	355 b	64 b	71 ab
Pennsylvania smartweed	1,585 b	0	2592 ab	0	49 bc	NA[b]

[a]Values within a column not followed by letters in common differ significantly (p = 0.05) according to ANOVA.

[b]Indicates that neither viable nor non-viable seeds were collected.

assigned to positions that were as close as possible to the middle of the board trap (i.e., approximately the center of the interrow area between two corn rows), yet not overlap one another.

Traps remained in place until corn harvest, at which time they were moved from interrows to within adjacent corn rows to trap seeds dispersed by the harvester and avoid damage by the harvester's tires. We judged that this necessary movement of the traps did not alter the differential seed entrapment capabilities among the trap types. After corn harvest weed seeds were categorized as described previously. Based on the area of the trap opening, all values for seed counts were converted to densities/m². Each trap type was rated subjectively for ease of processing samples on a scale of 1 to 5, with 1 being most difficult and 5 being easiest.

Utility of seed traps for estimating actual seed shed was judged in two manners for the five most important weeds in the study. First, the mean and coefficient of variation (CV[4]) of seed density was calculated for each species in each type of seed trap, with the assumption that low CV's were associated with high reliability in seed trap design. ANOVA and LSD ($p = 0.05$) were used to determine differences in seed production among trap designs for each weed species (1).

The second evaluation of trap utility assumed that true seed production depended upon both the number of weeds and the size of the weeds. Therefore, coefficients of determination (r^2)[4] were calculated for multiple regressions (1) of seed production (dependent variable) as a function of weed density and dry-weight (independent variables) in July. Seed traps associated with high r^2 values were assumed to have higher predictive ability than those associated with low r^2 values.

RESULTS AND DISCUSSION

Five weed species produced enough seeds in 1993 and/or 1994 for analysis. These species were robust forms of green foxtail[5], redroot pigweed, common lambsquarters, wild mustard, and Pennsylvania smartweed. Seeds of wild proso millet were found in a single plot in 1994, and phenological results are shown for this species solely for comparative purposes.

Seasonal summations. The five species, combined, annually produced from 15,000 to 34,000 seeds/m². Green foxtail produced more seeds than all other species combined, 25,600 seeds/m² in 1993 and 14,000 seeds/m² in 1994 (Table 1). Green foxtail also also had the highest densities of adult plants each year (Table 2). Production of viable seeds was greater in 1993 than in 1994 for all species except redroot pigweed. Production of non-viable seeds generally followed the same trends as that for viable seeds. Some species produced appreciable quantities of non-viable seeds.

Percentages of total seed production that were considered viable seeds varied considerably by species, especially in 1993 (Table 1). The percentage of viable seeds was greatest for green foxtail, for which about 79% of the seeds were viable in both years. In contrast, only 11% of redroot pigweed seeds were viable in 1993, but this value was 59% in 1994. Viable seed percentages did not differ ($p > 0.18$) between years for other species, averaging 48% for

[5]In west central Minnesota green foxtail populations consistently exist as mixtures of two taxa recognized by WSSA: robust purple foxtail (*Setaria viridis robusta-purpurea* Schreiber) and robust white foxtail (*Setaria viridis robusta-alba* Schreiber). These forms probably are merely color variants of the same taxon, and therefore we refer to both simply as the robust form of green foxtail.

Table 2. Post-cultivation weed densities and aboveground dry-weights in early July, 1993, and late July, 1994; and associated CV values (in parentheses) as indicators of among-plot variability.

	1993	1994	1993	1994
	plants/m^2		g/m^2	
Green foxtail	358 a[a] (29)	552 a (38)	62 b (20)	455 a (18)
Redroot pigweed	16 b (83)	8 b (52)	5 b (37)	76 b (37)
Common lambsquarters	30 b (57)	14 b (40)	11 b (59)	37 bc (38)
Wild mustard	31 b (42)	5 b (100)	179 a (64)	29 bc (71)
Pennsylvania smartweed	14 b (148)	1 b (173)	15 b (146)	1 c (173)

[a]Values within columns not followed by letters in common differ significantly (p = 0.05) according to ANOVA.

common lambsquarters, 68% for wild mustard, and 49% for Pennsylvania smartweed. In the single plot in which wild proso millet occurred, viable seeds of this species represented 76% of total seed production (557 seeds/m^2).

For comparison, corn grain yield in these same plots averaged 2150 kg/ha in 1993 and 6815 kg/ha in 1994 (5). Low yields in 1993 were associated with abnormally low growing season temperatures, whereas excellent conditions for corn growth occurred during the 1994 growing season (Figure 2). Corn yield was inversely related to total weed seed production (Table 1).

Phenological patterns of seed shed. The onset and duration of seed shed differed between years and among species (Figure 3). Seed shed began about 3 wk later in 1993 than in 1994, almost certainly due to the relatively low temperatures and cumulative GDD in 1993 as opposed to 1994 (Figure 2). Although the number of calendar days differed appreciably between years for onset of seed shed, GDD values for specific seed shed percentages were similar between years. For example, at 25% cumulative seed shed, GDD values for each species in 1993 and 1994 were as follows: green foxtail, 1009 and 1058; redroot pigweed, 1015 and 1052; common lambsquarters, 984 and 982; wild mustard, 984 and 984; Pennsylvania smartweed, 1004 (in 1993); and wild proso millet, 951 (in 1994).

Although cumulative seed shed was associated generally with cumulative GDD, brief pulses of dispersed seeds may have been related to specific wind storms. For example, maximum wind speeds on Aug. 23, 1994 (DOY[4] 235) reached 18 m/s, and this was associated with a large increase in seed shed, especially of the early maturing species: wild mustard, wild proso millet, and common lambsquarters (Figure 3). During 1993, windy days on or near DOY 256 were associated with large numbers of shed seeds for wild mustard and common lambsquarters; and wind on or near DOY 273 may have caused extensive shedding of seeds of Pennsylvania smartweed, green foxtail, and redroot pigweed.

Combine harvesting resulted in a final and sudden rise in the shedding of viable seeds (Figure 3). In the cool year of 1993, harvesting was delayed until October 20 to allow corn grain to dry. Despite this delay, all weed species retained appreciable percentages of viable seeds in their infructesences, which passed through the combine. Of the total viable seeds that were produced during the year, the percentages retained until harvest were 32, 21, 34, 31, and

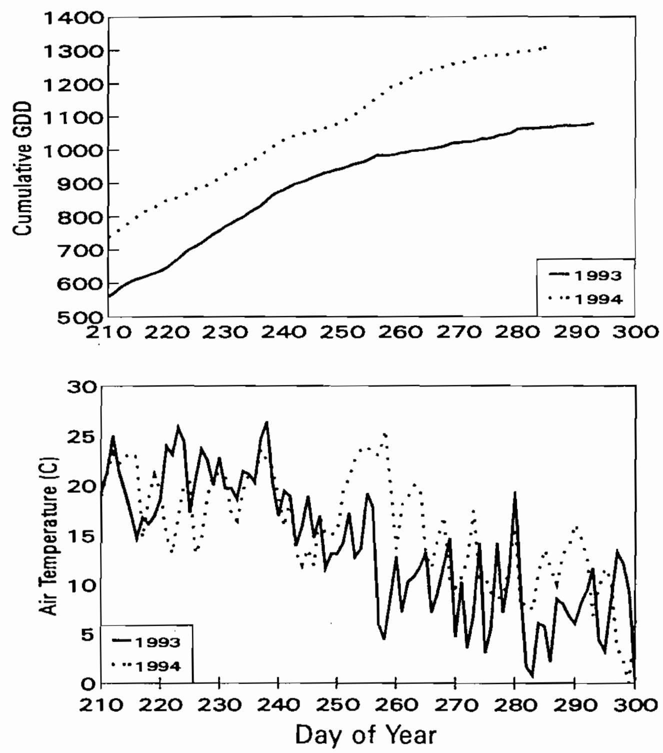

Figure 2. Cumulative growing degree days (base 10 C) from date of planting corn in May until corn grain harvest in October, and average air temperatures during the seed dispersal seasons of 1993 and 1994, near Morris, MN.

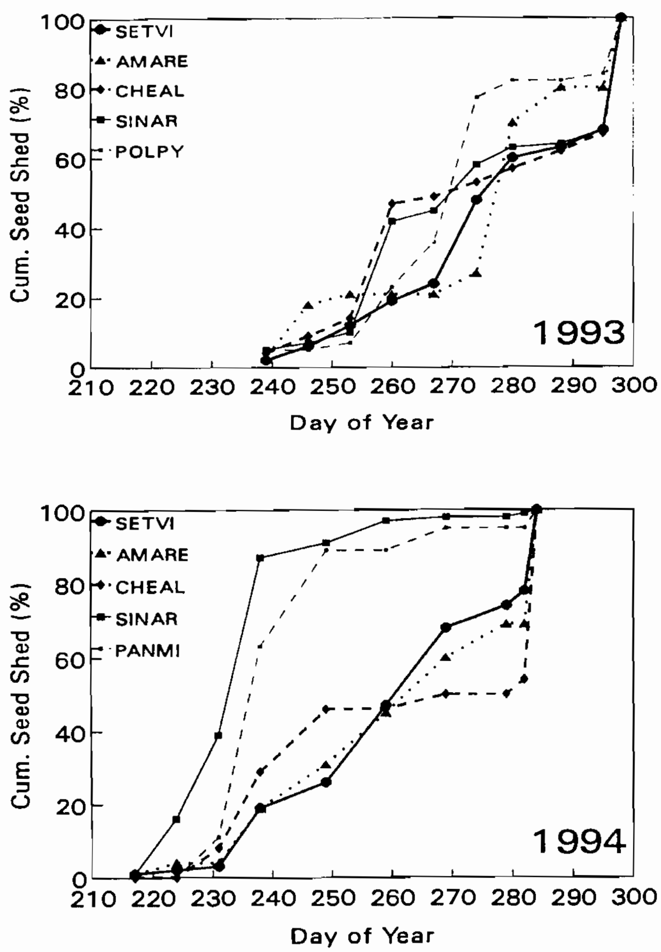

Figure 3. Cumulative shedding of viable (filled) weed seeds in corn during the seed dispersal seasons of 1993 and 1994, near Morris, MN. Percentage values represent the number of viable seeds shed at intervals divided by the total number of viable seeds shed during the entire season, multiplied by 100. The difference between the last and next-to-last values represents seeds dispersed by combine harvesting. Species abbreviations are as follows: SETVI, green foxtail; AMARE, redroot pigweed; CHEAL, common lambsquarters; SINAR, wild mustard; POLPY, Pennsylvania smartweed; and PANMI, wild proso millet.

16% for green foxtail, redroot pigweed, common lambsquarters, wild mustard, and Pennsylvania smartweed, respectively. In 1994, which was warmer than 1993, corn was harvested on October 12. Percentages of total viable seeds produced during 1994 that were retained by infructesences until combine harvested were 22, 31, 46, 1, and 5% for green foxtail, redroot pigweed, common lambsquarters, wild mustard, and wild proso millet.

For early maturing species, like wild mustard, and perhaps, wild proso millet, rapid plant maturation during warm years resulted in nearly complete dispersion of seeds prior to crop harvest. During cool years, some seeds of such species were retained in infructesences until harvest. In contrast, more than one-fifth of all viable seeds produced by green foxtail, redroot pigweed, and common lambsquarters were retained and dispersed at harvest regardless of weather conditions during the growing season. Haas and Streibig (6) reported that many common lambsquarters seeds remained in infructesences until harvest and were dispersed by combines. Consequently, this made the combine an important source of weed dispersal. If combines could be modified to retain weed seeds after separation from crop grain, and prevent these seeds from replenishing the seed bank, this machinery could be an important potential method of weed management.

Seasonal changes in seed viability. At each sampling date the seeds of each species were separated into two categories: viable (whole or filled seeds) and non-viable (empty, hollow, and/or unfilled seeds). In general, percentages of viable seeds were relatively low for all species at the beginning of the seed dispersal season in both years (Table 3). Perhaps early abscission of unfertilized ova and/or aborted seeds eliminated allocation of resources to failed reproductive structures. Percentages of viable seeds in-

Table 3. Average viability of seeds collected in seed traps at different days of the year during 1993 and 1994 for five weed species growing in corn near Morris, MN.

DOY	Green foxtail	Redroot pigweed	Common lambs-quarters	Wild mustard	Pennsyl-vania smartweed
			%		
1993					
239	50	17	53	30	11
246	93	63	92	46	18
253	86	50	77	52	26
260	92	NA[a]	93	70	31
267	83	NA	100	58	67
274	84	54	85	74	72
280	81	6	63	85	50
288	66	11	60	92	33
295	83	0	44	87	83
298	76	8	31	88	90
1994					
217	78	33	NA	25	NA
224	88	89	0	95	NA
231	68	NA	100	44	NA
238	84	67	83	78	NA
249	85	84	67	83	NA
259	81	54	0	61	NA
269	70	51	50	100	NA
273	75	35	0	NA	NA
282	82	0	100	NA	NA
284	69	59	78	100	NA

[a]Indicates that neither viable nor non-viable seeds were collected.

Table 4. Comparison of five different types of seed traps for estimation of viable seeds in terms of densities, fecundities, and coefficients of variation (CV) for five weed species in 1993. Lowest CV among trap designs for each species is in bold.

	Seed trap design				
	Cup	Funnel	Trough	Dish	Board
	seeds/m^2				
Density					
Green foxtail	19,136 a[a]	19,456 a	21,070 a	12,523 b	3,341 c
Redroot pigweed	1,067 a	577 a–c	693 ab	468 bc	93 c
Common lambsquarters	4,325 a	1,937 ab	2,648 ab	1,467 b	405 b
Wild mustard	3,877 a	2,905 b	2,355 b	2,578 b	1,182 c
Pennsylvania smartweed	2,502 a	1,155 a–c	1,971 ab	768 bc	509 c
	%				
CV					
Green foxtail	29	46	33	38	**17**
Redroot pigweed	**20**	85	120	72	89
Common lambsquarters	87	89	84	77	**39**
Wild mustard	20	24	30	**10**	45
Pennsylvania smartweed	**71**	111	115	81	88
	seeds/plant				
Fecundity					
Green foxtail	56 a	55 a	60 a	35 b	10 c
Redroot pigweed	124 a	60 ab	70 ab	42 b	10 b
Common lambsquarters	214 a	89 bc	127 ab	73 bc	23 c
Wild mustard	172 a	133 ab	109 bc	124 ab	51 c
Pennsylvania smartweed	655 a	178 b	300 ab	171 b	105 b
	%				
CV					
Green foxtail	**31**	40	27	24	33
Redroot pigweed	**63**	82	118	82	80
Common lambsquarters	70	**66**	69	68	74
Wild mustard	**70**	77	80	81	72
Pennsylvania smartweed	93	81	111	80	**72**

[a]Density and fecundity values within a row not followed by letters in common differ significantly ($p = 0.05$) according to ANOVA.

creased subsequently, but in a highly erratic manner for most species.

Green foxtail was the exception among the species because its percentage of viable seeds remained relatively stable over time (Table 3). For other species, percent viable seeds varied considerably across sampling periods during both 1993 and 1994. For example, percentage viable seeds of redroot pigweed and common lambsquarters varied from 0 to > 90% during the 1994 dispersal season, with no obvious temporal trends. Still other species, such as wild mustard and Pennsylvania smartweed, exhibited trends of increasing viable seed percentages as the dispersal season progressed, possibly due to a positive response of pollination and/or seed development to decreasing air temperature during August and/or September (Figure 1) for these species.

Despite the aforementioned trends, reasons for the high variability in viable seed percentages remain uncertain. Any number or combination of single-day events could have disrupted anthesis and/or seed maturation and resulted in the observed variation: e.g., first frost of the season, high-temperature stress, water stress, and wind storms. Regardless of the cause of this variability, the simple existence of such high variability in viable seed percentages during seed dispersal is the most important result from this section of the study. For example, based on these results, we conclude that sampling protocols for seed viability studies need to consider multiple times of sampling to capture the true variation in seed viability expressed by a weed species over the course of the season of seed dispersal.

Comparison of seed traps. Estimated seed densities tended to be greater for seed traps with side walls exceeding about 2 cm, i.e., the cup, funnel, and trough (Table 4).

Table 5. Coefficients of determination relating weed density and dry-weight (independent variables) in July to seed production as measured in five types of seed traps. Values greater than 0.90 are in bold.

Species	Seed trap design				
	Cup	Funnel	Trough	Dish	Board
	r^2				
Green foxtail	**0.93**	0.71	**0.99**	0.81	0.52
Redroot pigweed	**0.93**	0.22	0.01	0.08	0.22
Common lambsquarters	0.85	0.86	0.88	0.82	**0.96**
Wild mustard	0.61	0.20	**0.97**	0.03	0.50
Pennsylvania smartweed	**0.90**	**0.96**	0.89	**0.96**	**0.93**

Highest seed densities were consistently estimated from the cups, and lowest densities consistently estimated from the sticky-board traps. The reason for this may be that individual seeds and/or pieces of infructesences that fell from parent plants onto low-walled seed traps (adhesive-covered dish and board) subsequently were dislodged from the adhesive surfaces, resulting in low estimates of weed seed production. Seed removal by small animals also may have been greater in low-walled traps than in taller traps, although the abundance of seeds on the soil surface throughout the plots should have diminished any differential attractiveness of the traps as food sources. Fecundity estimates varied in a similar manner to those of seed density (Table 4).

The CV's associated with seed trap estimates of density $(CV_{td})^4$ and fecundity $(CV_{tf})^4$ provided indices of how well seed traps captured seeds. CV_{td} and CV_{tf} can be compared to the variability associated with adult weed density $(CV_{wd})^4$ and dry weight $(CV_{ww})^4$ in the same plots (Table 4). Because the experimental plots were untreated check plots from another experiment (5), the early-summer density and dry-weight of the dominant weed, green foxtail, was high (358 plants/m^2 and 62 g/m^2) and relatively homogeneous among plots ($CV_{wd} = 29$ and $CV_{ww} = 20$). Efficient seed trap designs might be expected to have CV_{td} and CV_{tf} values less than or equal to those of CV_{wd}, and/or CV_{ww}. In contrast, inefficient trap designs might be expected to increase variability of seed production estimates relative to the variability of adult weed densities and/or dry weights. In the case of green foxtail, CV_{td} (Table 4) was lower than or equal to CV_{wd} (Table 3) only for the board ($CV_{td} = 17\%$) and cup ($CV_{td} = 29\%$) traps, suggesting that these traps, in comparison to the other three trap designs, reduced the variability of green foxtail seed production estimates relative to that of the spatial (among-plot) variability of green foxtail plants. Each trap design had at least one CV_{td} or CV_{tf} value that was less than or equal to those of associated CV_{wd} or CV_{ww} for a particular species. However, the plastic cup trap had lower CV_{td} or CV_{tf} values for more species than other traps, indicating that it may be an efficient trap design.

The second method, used to judge predictive ability of seed traps, was multiple regression of seed density (dependent variable), estimated from each seed trap design, on weed density and dry weight (independent variables) of the appropriate weed species. The resulting r^2 values (Table 5) provided indications of how much variation in seed production estimates from each trap design could be attributed to weed density and weed dry-weight, two logical determinants of seed production.

Each seed trap design was associated with the highest r^2 value for one species: the trough for green foxtail, the cup for redroot pigweed, the board for common lambsquarters, the trough for wild mustard, and both the funnel and dish for Pennsylvania smartweed (Table 4). However, the plastic cup had more r^2 values ≥ 0.90 than any other trap design. Moreover, the plastic cup was not associated with any r^2 value ≤ 0.60, unlike other trap designs.

Ease of processing seed samples from each trap design differed markedly. Both types of sticky traps (dish and board) scored 1 (most difficult), the trough scored 4, and the funnel and cup both scored 5 (data not shown). Although large, viable seeds could be removed relatively easily from sticky traps, small seeds and non-viable seeds were difficult to count and remove. Also, transporting sticky traps to and from the field demanded special handling to prevent traps from contacting one another and other surfaces. Troughs scored lower than the cup and funnel because of awkwardness in transporting them, erecting them in the field, and collecting seeds from them. The funnel and plastic cup scored highest because they transported easily (stacked one upon the other), and seeds, once trapped, were easy to access. The low cost of the plastic cup (with brass screen and wooden stake) was considerably lower than that of the funnel, and consequently was preferred over the funnel.

We conclude from these results that each seed trap design may have value in some situations. However, the plastic cup design was preferred because it trapped high densities of seeds with relatively low among-plot variation, its seed density estimates were highly correlated with weed density and dry-weight, it was easy to assemble, it cost little, and its resulting seed samples were easy to process.

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